Water Ice and Methane Formation in the Planet-Forming Regions of Circumstellar Disks

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Abstract

We present preliminary results from our models of ice formation and chemistry in the interior, cold midplane regions of circumstellar gaseous disks. We extend our thermo-chemical disk models which calculate the thermal, density and chemical structure of disks by considering the heating and cooling of gas and dust separately (Gorti & Hollenbach 2004, 2007), and now include ice formation and grain surface reactions in our steady-state disk chemistry.

CO is the thermodynamically stable form of carbon in the interstellar medium and in the cold, outer regions of disks where it is frozen as ice. As dust grains get warmer closer to the central star, ($T_d > 20$ K; inward of $\sim 50 - 100$ AU) CO ice vaporizes off dust grains. In our steady-state disk chemical models, we find that in this region the destruction of gas-phase CO by He^+ can lead to the conversion of oxygen in the disk to water ice on grains, and the carbon is either in CH_4 ice ($T_d < 40$K, or $r > 20$ AU) or in more carbonaceous ices with higher sublimation temperatures. There is thus an enhanced abundance of methane in the $\sim 3 - 50$ AU regions of disks. We predict the formation of distinct ice belts in the disk, with CO frozen on grains at large disk radii ($\sim>$ 40AU, where $T_d < 20$), a CH_4 ice belt at intermediate radii ($\sim 20 - 40$ AU, where 20 K $< T_d <$ 40K) and other carbon ices inward of $\sim$ 20 AU up to the snow line. H_2O ice exists outside the snow line ($\sim$ 5 AU), but is enhanced in the region from the snow line up to $\sim$20 AU due to the breakdown of CO.

Our results have implications for the formation of planetesimals and planets in disks. Increased ice abundances near the snow line will increase the solid/gas ratio in the formation zones of giant planets, and may shorten their formation timescales. The spatial and temporal distribution of ices formed in the protosolar disk will also impact the chemical composition of the objects (planets, satellites and other minor bodies) that are assembled, and may explain, for example, the CH_4 abundance in Titan.